Characterizing and Correcting Hyperion Detectors Using Ice-Sheet Images

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***Abstract*—Two Hyperion images of the Greenland ice sheet are used to characterize errors in the visible near-infrared (VNIR) and shortwave infrared (SWIR) detector arrays of Hyperion. Spatial variability in detector output is seen in both arrays and, in both cases, is largest at the shorter wavelengths and decreases as wavelength increases. Standard deviations of the maximum variability are 40 digital numbers (DNs) for the VNIR array and 123 DNs for the SWIR array. Based on a single pair of images, temporal stability is nearly as large and exhibits the same spectral characteristics of large variability at shorter wavelengths and decreasing variability with increasing wavelength. The uniformity and stability of the ice-sheet surface enables a detailed characterization and emphasizes the utility of using ice sheets as targets to achieve on-orbit sensor characterization.**

***Index Terms*—Calibration, hyperspectral, ice sheets, image sensors.**

I. Introduction

HYPERION is the first satellite-based hyperspectral sensor. Launched in November 2000, on the Earth Observing 1 (EO-1) platform, it is part of the National Aeronautics and Space Administration New Millennium Program whose goal is to develop and demonstrate new technologies for space-based research. In the case of the EO-1 program, a science validation team was established to investigate the utility of Hyperion and two other instruments (Advanced Land Imager and Leisa Atmospheric Corrector) for earth science studies. The lead author was a team member and led a set of coinvestigators whose assessments included a wide range of applications on snow and ice [1]. Many images of ice sheets were collected to support these studies.

Distinct from the glaciological applications of the EO-1 sensors, the nearly homogeneous reflectance of the ice-sheet surface also provides an opportunity to characterize the imaging instruments with a natural "flat-field" target. As its name implies, a "flat field" target is devoid of features and should produce a uniform image. Deviations from uniformity, therefore, can be attributed to various aspects of the imaging system. This paper reports on this characterization of the Hyperion detectors, including the stability of the detectors, and illustrates a means to correct for the detector variations found.

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II. Hyperion

Hyperion is a pushbroom-type sensor that measures the incoming radiation at the instrument across 220 spectral bands in the 400–2500-nm wavelength range with a spectral resolution of 10 nm *(http://eo1.gsfc.nasa.gov)*. Images are collected of the earth with a spatial resolution of 30 m across a swath 7.5 km wide. This is accomplished by recording the spatial and spectral information on two multidetector arrays. A charged-couple device (CCD) spectrometer produces the first 70 channels in the visible and near-infrared (VNIR) wavelengths (400–1000 nm), while a HgCdTe spectrometer produces channels 71 through 242 in the shortwave infrared (SWIR) wavelengths (900–2500 nm). Both spectrometers share the same fore-optics.

The spectrum for each 30-m pixel across the swath is measured by a separate set of detectors. Ideally, the detectors for every pixel respond identically in their analog-to-digital characteristics, but this is never achieved, in practice. Prelaunch calibration of this array determined corrections to account for detector variability. These corrections were applied during Level 1 processing of Hyperion data performed at TRW, the Hyperion instrument manufacturer.

III. Ice-Sheet Data

Hyperion data of ice sheets were collected for purposes ranging from albedo determination to cloud/snow discrimination [2], [3]. Here we use images of extremely homogenous regions of the ice sheet to minimize target-related variations in Hyperion data. The large extent of these homogenous areas further promotes their use as a "flat-field" target when lines of image data across the image swath are averaged along the groundtrack. By this approach, we can attribute spatial variations to detector variability of the Hyperion instrument.

The two Hyperion images used in this paper were collected from the "Crawford Point" site in western Greenland (69.88°N, 46.98°W) on July 7, 2001 (day 188) and 32 days later on August 8, 2001 (day 220). At this site, the surface is composed exclusively of very gently undulated topography with a mean surface slope of approximately 0.5° and surface reflectivity variations of less than 1%. The uniform character of this surface extended across the entire swath (256 pixels). Along the groundtrack, this surface persisted for 3500 lines (105 km) in the day 188 image, but was limited by clouds to 236 lines (7.08 km) in the day 220 image.

The scaled spectral radiances of these image subsets are shown in Fig. 1 (in digital number (DN) units). Throughout the paper, we present our results in terms of scaled spectral radiance. This decision makes effects in the SWIR region,

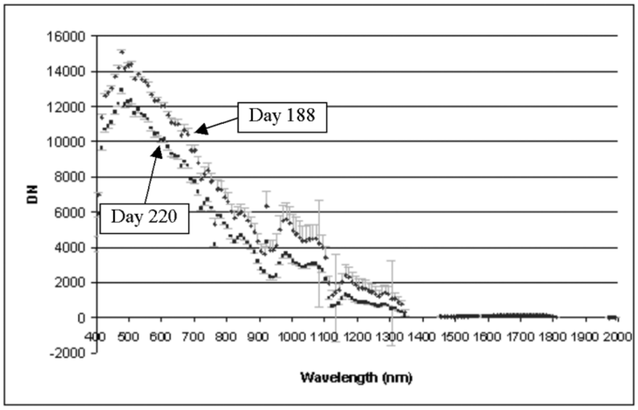

Fig. 1. Scaled spectral radiances (in units of DN) for the uniform images subsets analyzed in this paper. Points indicate the mean values for each image, and vertical bars indicate the standard deviations.

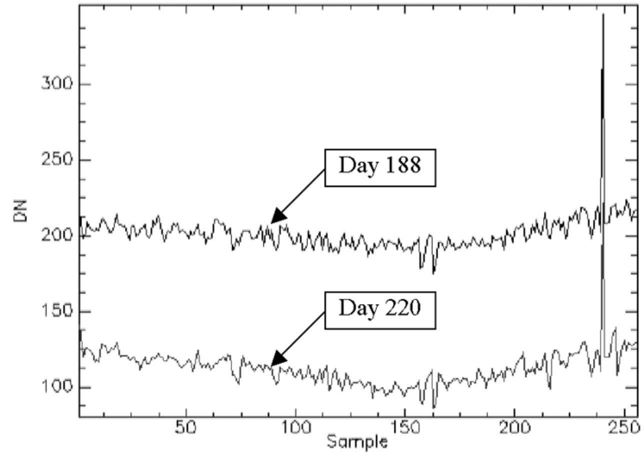

Fig. 2. Averaged line profiles of both images for band 120 (1346 nm). Anomaly at pixel 240 illustrates presence of an unreliable detector. Data at this pixel location were corrected as discussed in text.

where snow radiance is low, easier to see and is closer to the native sensor units. Actual radiance can be derived by dividing the VNIR bands by 40 and the SWIR bands by 80. The day 188 image is brighter, probably due to a higher sun elevation (closer to the summer solstice) and possible atmospheric differences. Atmospheric differences on the two dates also might contribute to the pixel-to-pixel differences, but the high degree of correlation in the inferred sensor characteristics shown later suggests this effect is not of primary importance.

The uniform nature of the ice-sheet target enhances the ability to see stripes in both images parallel to the satellite ground track. The magnitude of the standard deviations in Fig. 1 is largest in the near infrared, where it reaches 1000 DN, and may indicate the presence of atmospheric water vapor. At longer wavelengths, the radiances range over a few hundred DNs. In the visible portion of the spectrum, standard deviations range over a few tens of DNs. Histograms (not shown) of the scaled radiances in the more reflective bands for snow have a half width of approximately 100 DNs (116 DNs for the most reflective band 13 at 478.4 nm). We show later that the magnitude of uncorrected detector outputs can be as large as a few tens of DNs, a magnitude comparable to the range of the scaled radiances. This explains why the stripes are so easily seen in images of uniform targets, such as the ice-sheet images considered here.

VI. Conclusion

Ice-sheet imagery provides an excellent target for characterizing the internal variability and temporal stability of the VNIR and SWIR Hyperion detector arrays. The image data appear to be extremely uniform when averaged even over short distances of a few hundred pixels. The spectral signatures also appear stable in time, with differences most likely due to a combination of sun elevation and possibly meteorologically induced changes to the surface snow.

Our analysis shows that variability of the Hyperion detector arrays occurs across the swath direction, in the spectral dimension and also in the temporal dimension. At a given spectral position, the variability of the detector error across the swath is roughly of the same magnitude as the temporal stability of the detectors. This variability is greatest at the shorter wavelengths of both the VNIR and SWIR detector arrays. This variability causes stripes in the imagery, but the effect can be almost completely removed if suitable corrections, recoverable from the imagery itself, are applied to the specific scene. Line-averaging is a useful means to determine suitable corrections, but due to the temporal variability of the detectors, these corrections must be determined either from each image being corrected or from an image taken very soon before or after the scene to be corrected. This can make it difficult to establish such precise corrections for most Hyperion imagery. Other suitable calibration sites might include deep water or salt flats.

The temporal characterization is limited by the use of only two scenes in this analysis. More ice-sheet scenes would strengthen the temporal characterization. Spectrally different targets, especially ones that are dark in the VNIR and bright at wavelengths longer than 1100 nm, if available, also would be useful. In lieu of such analysis, the variability reported here should be considered a useful guide to temper the overinterpretation of very slight spatial or temporal changes in Hyperion data.